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Evaluation of Water-Use Needs in the Electricity Generation Sector of Greece

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Abstract

Water conservation needs encourage -among others- the investigation of water use in the electricity generation sector. To this end, we currently determine the amounts of water used in thermal electricity generation for both cooling and energy generation purposes, presenting at the same time the respective water needs of renewable energy sources (RES) plants. Furthermore, special attention is given to the country of Greece, for which we evaluate the local power stations' performance in relation to the local fresh water potential. The study is concluded by realizing that promotion of RES power generation will ensure -apart from the satisfaction of other energy and environment-related targets- conservation of valuable water resources in some of the most vulnerable areas of the Greek region.

Keywords

Water Resources; Water Scarcity; Thermal Power Generation; Renewable Energy Sources

Introduction

Water is a scarce natural resource, with human population increasingly putting further pressure on clean water resources. In fact, it is more than one billion people that do not have access to clean water resources nowadays. Electricity at the same time is also a vital social good that strongly determines the quality of everyday life. Similar to water use, both increase of population and amelioration of living standards in the most populated areas of the planet during the recent years (e.g. China and India) call for the constant increase of the installed electrical power capacity. Simultaneously, in many regions of the developed world, the industrial sector (including also the electricity generation sector) is found to comprise the dominant water user (Bierbaum et al., 2012; WRI, 2001), with high water stress levels in many of these areas (UN, 2008) requiring conservation of local water resources. To this end, most of contemporary power generation technologies absorb substantial amounts of water, mainly used for cooling purposes in case of thermal power stations (TPSs), and may hence be characterized as water-intensive. On the other hand, renewable energy sources (RES) power plants exhibit far lower water needs per unit energy produced, thus allowing for the satisfaction of other pressing water needs.

At this point, one should also note that the water used in electricity generation is usually divided into two types of uses (EEA, 2012), i.e., withdrawal and consumption. In the first case, although water may be returned entirely to the withdrawal source, depreciation of its quality is expected in most cases. On the other hand, in case of water consumption, the amount of water withdrawn is no longer available for use because it has evaporated, transpired, incorporated into products and crops, consumed by man or livestock, ejected directly into the sea, or otherwise removed from fresh water resources.

Acknowledging the above, an effort is currently undertaken to collect data concerning water needs per unit energy produced (e.g. lt or m^3 of water per MWh_e) for the most common electricity generation technologies. For this purpose, data determining the operation of representative TPSs, concerning both energy generation and cooling needs, are collected and analyzed in order for the respective water requirements to be estimated. In addition, the corresponding water requirements of the most mature RES technologies are presented, so as to validate the assumption of minimum water needs in comparison with the respective of TPSs.

Next, the case of Greece is examined, considering that the country lies on a region of vulnerable water resources, facing the threat of desertification for a large part of its area and relying almost exclusively on thermal power generation for the satisfaction of electricity consumption.

Materials and Methods

As already mentioned, water use in the electricity generation sector mainly refers to cooling and energy generation needs of TPSs. On the other hand, although not as important, RES power generation also requires - on top of other impacts (Kaldellis et al., 2003)- considerable amounts of water, with its use however mainly noted in the stages of manufacturing and construction. The same is of course not valid in the case of biomass or geothermal power, where irrigation requirements on the one hand (Berndes, 2002) and cooling needs on the other (Coskun et al., 2011) (since the geothermal condensate will normally not provide sufficient cooling) are the main sources of water consumption. On the contrary, water needs in the case of photovoltaics (PVs) are recorded mainly during the manufacturing stage, although water is also needed during operation for cleaning or even cooling purposes (He et al., 2011). Similar is the case for wind energy, where the requiring stages of manufacturing wind turbines and constructing a wind farm imply considerable water demand (Vestas, 2006). Finally, in the case of hydropower, the net drawing of water during operation is usually considered to be almost zero (Kenny et al., 2009), with the use of water during the construction stage being comparatively lower than that of other RES technologies.

In this regard, water use data for both thermal and RES power generation are currently adopted from Fthenakis and Kim (2010), while to further validate results obtained concerning TPSs, additional data are also used from several power stations operating in the UK and the USA, i.e., two regions where industrial activity is the main responsible of water use, partly owed to the operation of thermal power plants. At this point, it must also be noted that in the specific countries one may encounter all types of TPSs, including also nuclear, considering at the same time that both more traditional and cutting edge technology is employed and thus the sample may be granted as representative of the nowadays and near future situation.

Besides that, the UK entering a stress period concerning fresh water availability (UN, 2008) sets an interesting case study in relation to the water use performance of local power stations. Furthermore, emphasis is given in the current study on the country of Greece. More specifically, through the adoption of a regional approach, evaluation of the water consumption needs of major Greek TPSs in relation to the water vulnerability of different Greek areas is undertaken, leading to the identification of priority-TPSs that could be substituted by less water-demanding technologies such as RES-based power plants. In this context, we determine the specific water needs of Greek thermal based power plants, using water needs along with the respective annual energy yield, and associate the results obtained with desertification risk levels and water supply/demand balance data of the regions where the examined Greek thermal power plants operate. Through this process, we designate the thermal power plants that need to be replaced in priority, and stress the importance of exploiting indigenous RES to do so.

Results and Discussion

Water Use in Thermal Power Generation

Considering the above, in Figure 1 one may obtain the life-cycle water needs of different types of TPSs (Fthenakis and Kim, 2010), considering also different types of cooling systems (i.e., once-through, recirculating and cooling pond).

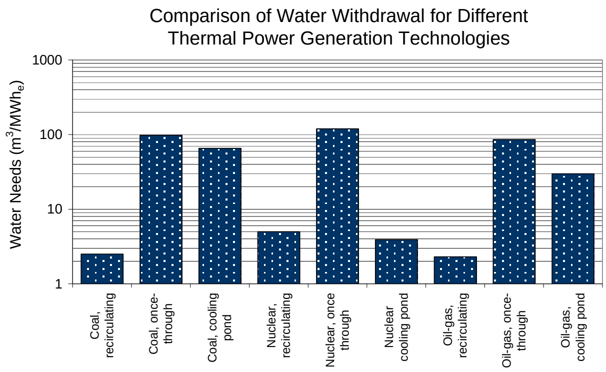

FIG. 1 WATER WITHDRAWAL OF DIFFERENT TYPES OF TPSs ON A LIFE-CYCLE BASIS

As expected, once-through systems suggest the greatest water withdrawal, while use of recirculation remarkably drops water withdrawal needs, even below 2.5m^3/MWh$_e$, excluding however nuclear power with 5m^3/MWh$_e$. The situation is inversed however in the case of cooling ponds, where nuclear power exhibits the lowest requirements (in the order of 4m^3/MWh$_e$), with coal power stations presenting a

value of 65m³/MWhₑ, close to the once-through, yielding water requirements of approximately 100m³/MWhₑ. The respective value for nuclear power stations is 120m³/MWhₑ, while finally, oil-gas power stations are determined by relatively lower water needs if once-through systems are adopted, i.e. in the order of 86m3/MWhe.

Accordingly, data collected from UK (Environmental Agency, 2010) and USA (NETL, 2010) TPSs are presented in Figures 2-4. More precisely, in Figure 2 one may obtain the total water needs of TPSs operated in the UK, in relation to both plant scale and type of technology employed. In this regard, as it may be concluded, there is a gradual reduction of the specific water needs as the plant capacity increases, which also coincides with the shift between different technologies. More precisely, smaller scale nuclear power stations seem to have the greatest water needs (from 1,300 to 2,700m³/kWₑ.a), followed by coal power stations of medium scale and finally oil power stations of large scale (even dropping below 700m³/kWₑ.a).

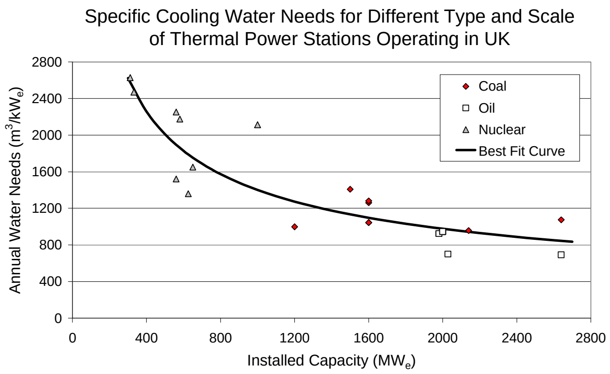

FIG. 2 COOLING WATER NEEDS FOR LARGE SCALE UK TPSs

At the same time, data available for USA power plants provide information on both withdrawal and consumption needs (see also Figures 3 and 4). According to the figures, scaling is again noted, this time in terms of annual energy production capacity.

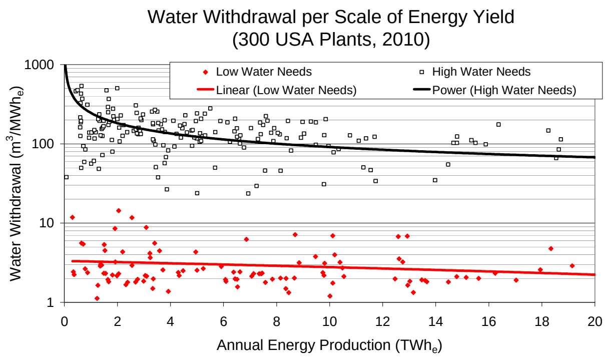

FIG. 3 WATER WITHDRAWAL NEEDS FOR USA TPSs

More specifically, significant scattering (from 1-1,000m³/MWhₑ) noted in the case of water withdrawal (Figure 3) suggests division in two groups of power stations (i.e., power stations of low and high water needs), determined by considerable scaling only in the case of high water withdrawal as the plant capacity increases. More precisely, specific water withdrawal even in the order of several hundreds of m³/MWhₑ for the smaller capacity plants is found to reduce to approximately 80m³/MWhₑ for the high water needs group, while in the case of the low water needs group, majority of power stations present water withdrawal of less than 3m³/MWhₑ. To this end, numbers provided are in total agreement with the data of Figure 1, reflecting at the same time the adoption of different cooling technologies among the two groups of TPSs. On the other hand, water consumption numbers (Figure 4) present appreciable concentration in the area of 10-100m³/MWhₑ, again exhibiting a scaling trend with the increase of TPS capacity.

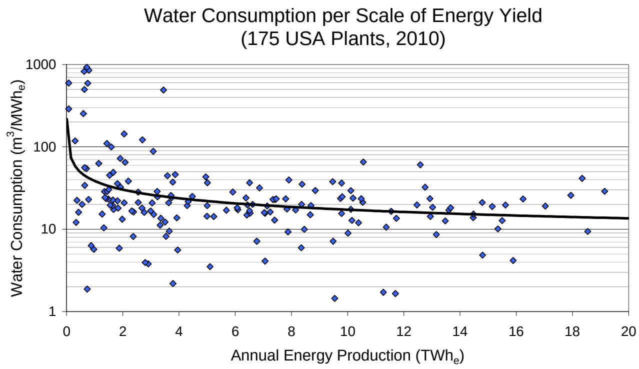

FIG. 4 WATER CONSUMPTION NEEDS FOR USA TPSs

Water Use in RES Power Generation

Next, water withdrawal needs of RES power generation technologies (Fthenakis and Kim, 2010) are given in Figure 5.

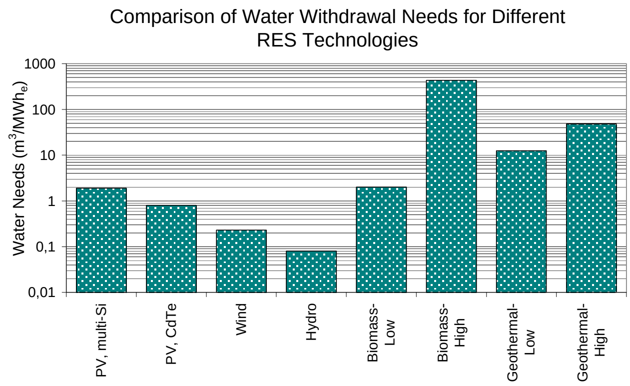

FIG. 5 LIFE-CYCLE WATER WITHDRAWAL NEEDS FOR RES TECHNOLOGIES

In this context, water needs of biomass crops and cooling requirements of geothermal plants present significant variation, much depending on the case each time studied (e.g. type of crop and type of soil for biomass and characteristics of the geothermal fluid in the case of geothermal plants), with the values of even the low water use scenario being either comparable to (in the case of biomass) or much higher than (in the case of geothermal plants) the numbers collected for thermal power generation and recirculating systems. On the other hand, wind power generation and hydropower plants are determined by considerably lower water withdrawal needs, i.e. 230lt/MWh_e and 80lt/MWh_e respectively, that clearly show the competitive advantage of the specific technologies, while finally, use of water for PVs is somewhat higher, even reaching 2m^3/MWh_e (i.e., similar to the case of the low water use biomass scenario). Besides, at this point one may also underline the fact that wind power is determined by rather low life-cycle energy requirements as well, opposite to the case of PVs, often accused of the comparatively higher energy payback periods (Kaldellis et al., 2012).

The Case Study of Greece

The electricity generation system of Greece (Kaldellis et al., 2008) may be divided into two main sectors, i.e., the mainland and the island sub-systems. As far as the mainland electricity grid (interconnected system) is concerned, centralized power generation based mainly on indigenous lignite reserves should be considered, while on the other hand, numerous isolated electrical grids of the island region (35 autonomous power stations (APSs) operating), on top of Crete island, rely mainly on oil imports (Kaldellis and Zafirakis, 2007). In this context, national dependence on fossil fuels is confirmed by the employment of approximately 6.1GW of steam turbines using indigenous lignite reserves (Kaldellis et al., 2009) and heavy oil (mazut) imports, 2.3GW of combined cycle power plants using imported natural gas, and a total of 1.3GW of oil based-generation (gas turbines and internal combustion engines) mainly used for the service of non-interconnected Aegean island grids.

Additionally, the mainland electricity grid is also supported by the operation of large hydropower plants (Kaldellis, 2008) that exceed 3GW and are used as peak shaving units (including two pumped hydro units of almost 700MW). Besides that, contribution of RES mostly derives from PV (~2.4GW) and wind energy applications (~1.8GW) (HWEA, 2013), while a small proportion corresponds to small-hydro (Kaldellis, 2007) as well as biogas and industrial waste installations. In this context, majority of Greek TPSs of the mainland -excluding three private, natural gas-based power stations- belong to the local Public Power Corporation (PPC), while on the other hand, APSs of island regions are exclusively operated by the PPC. In this regard, water needs of island APSs are almost solely covered with the use of saline water, although the same is not valid for the mainland TPSs, using in most cases fresh water. At the same time, water scarcity and desertification threatening several areas of the Greek territory, imply the need for water conservation or improved water management in every water use / consuming activity, including also the use of fresh water by TPSs. In this regard, operation sites of major Greek TPSs and APSs are found in Figure 6, where division of the Greek territory in water departments is also available (Koutsogiannis et al., 2008).

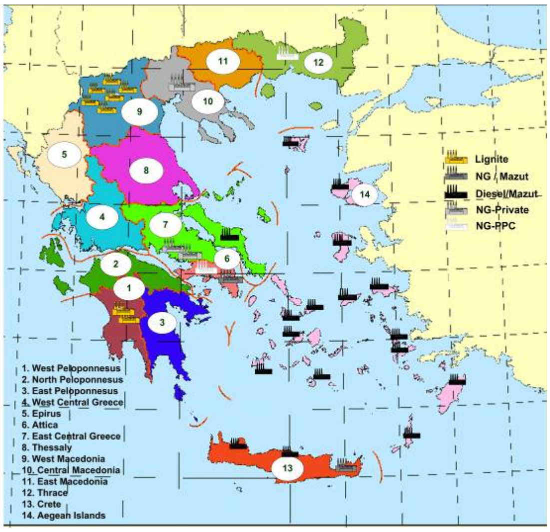

FIG. 6 DISTRIBUTION OF GREEK TPSS PER WATER DEPARTMENT

As one may obtain from the figure, majority of TPSs (in terms of installed capacity) are found in the regions of West Macedonia (department 9), Attica and East Central Greece (departments 6 and 7), as well as in West Peloponnesus (department 1), while concerning the island region, three major power stations using also amounts of fresh water to some extent operate on the island of Crete. Meanwhile, according to the map given in Figure 7 (GNCCD, 2002), the desertification problem is found to be more intense for the eastern part of the mainland and Crete, opposite to the case of West Macedonia. On the other hand, data provided concerning the regional balance of water demand and water supply for the month of

July, including also short- and long-term predictions, reveal the vulnerability of West Macedonia to water scarcity as well (Figure 8), with data concerning the rest of TPS regions reflecting a more severe situation.

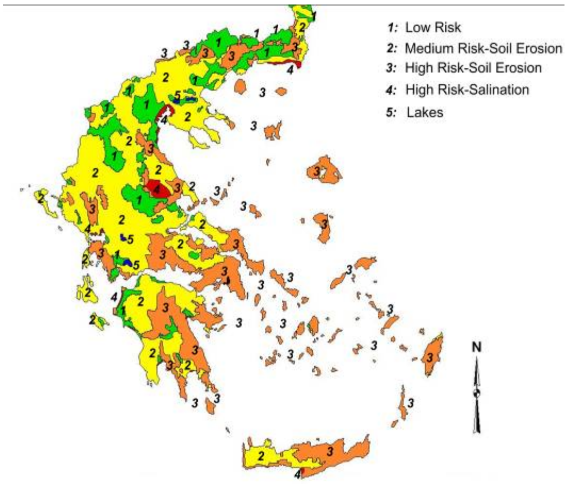

FIG. 7 MAP OF DESERTIFICATION RISK IN GREECE

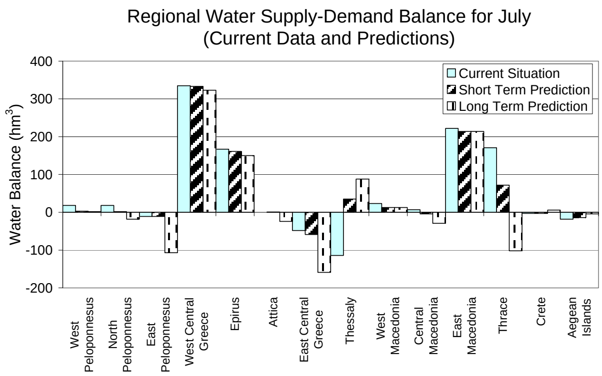

FIG. 8 JULY WATER SUPPLY-DEMAND BALANCE PER REGION

In this regard, annual water use per water department of the Greek territory is also provided in Figure 9. As one may see, irrigation is as expected comprising the main water use, followed by water supply. On the other hand, industrial use is restricted to West and Central Macedonia, with similar numbers attributed to water use by TPSs, concentrated in West Macedonia and West Peloponnesus.

More precisely, concerning fresh water use by major Greek TPSs (see also Table 1), the following should be considered according to the data provided by (Koutsogiannis et al., 2008):

- The West Macedonia TPS complex uses almost 90hm³ of fresh water per year, mainly for cooling purposes, which derives from the river of Aliakmonas (Polifitos lake) and from the lake of Vegoritida.
- The West Peloponnesus TPS complex uses approximately 18hm³ of fresh water per year, coming from local bores.
- The oil-based power stations of Lavrio (Attica) and Aliveri (Euboea) although using mainly saline water, also use fresh water in the order of 15,000m³/year, deriving from local bores and water mains.
- From the data available concerning Crete, the power station of Chania, which uses air-cooling, consumes fresh water for steam production in the order of 60,000m³/year, while the power station of Linoperamata uses approximately 160,000m³/year deriving from Almyros, for both cooling and steam production.

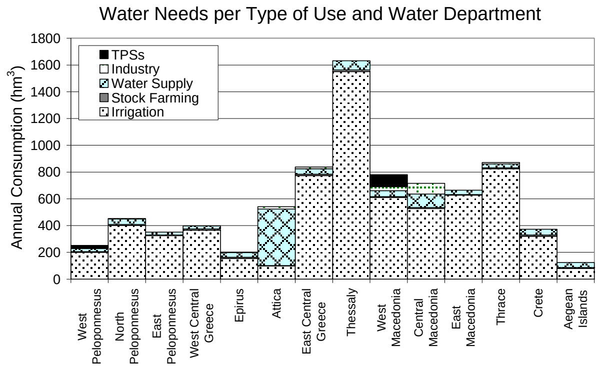

FIG. 9 BREAK-DOWN OF ANNUAL WATER CONSUMPTION PER REGION

TABLE 1 MAIN CHARACTERISTICS OF GREEK TPSs EXAMINED

TPS Region	Fuel	Installed Capacity 2007 (MW)	Energy Production 2007 (GWh)
West Macedonia			
Melitis	Lignite	330	2188
Ptolemaida	Lignite	620	2979
Aminteo	Lignite	600	3082
Kardia	Lignite	1250	7168
Agios Dimitrios	Lignite	1595	10596
Liptol (decom.)	Lignite	43	174
West Peloponnesus			
Megalopolis-A	Lignite	550	3097
Megalopolis-B	Lignite	300	1892
Crete			
Chania	Diesel	355	989
Linoperamata	Mazut-Diesel	284.2	959
Attica & Euboea			
Lavrio	Mazut-NG	1572	8486
Aliveri	Mazut	380	1366

To this end, by also taking into account the respective data of energy production of the specific TPS complexes for the year 2007 (PPC, 2009) (see also Table 1), the specific fresh water use may also derive. More

precisely, according to the results of Figure 10, lignite-based TPSs of West Macedonia and West Peloponnesus present the highest specific water use, in the order of 3,000-3,500lt/MWh$_e$, that however classifies them to the lowest rank of water withdrawal if considering international data previously presented.

Furthermore, partial fresh water use of Crete power stations yields a specific use of almost 0.1m3/MWhe, which is less than the life-cycle withdrawal needs of wind energy production, while finally, the TPSs of Lavrio and Aliveri together present a total of 1,500lt/GWh$_e$, clearly reflecting the almost exclusive use of saline water for their needs' satisfaction.

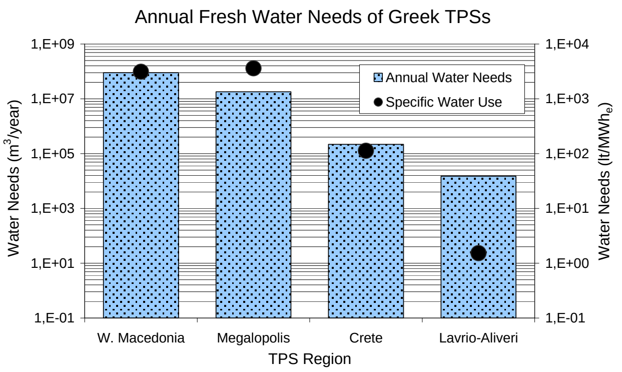

FIG. 10 ANNUAL WATER USE AND SPECIFIC WATER USE COEFFICIENT OF GREEK TPSs EXAMINED

Conclusions

Based on the evaluation of Greek TPSs concerning water use performance, lignite-fired power stations are as expected determined by the higher water use coefficient, corresponding however to the lower levels of specific water consumption deriving from international data. On the other hand, oil-based power stations of the mainland (Lavrio-Aliveri) and Crete are characterized by water use coefficients that are comparable to the ones attributed to RES power generation, owed, nevertheless, to the fact that they use inconsiderable amounts of fresh water in comparison to saline water. At the same time however, water stress levels noted in several areas of the Greek territory, including also the installation areas of TPSs using fresh-water, dictate water conservation that may well extend to the electricity generation sector as well. In this regard, investment on appropriate RES power generation projects may discharge water stress of those sensitive areas, even in the case that water use is minimum (such as in the case of Crete), while at the same time may lead to the accomplishment of national energy targets concerning RES penetration and pollution abatement. To this end, as previously seen, wind power projects and hydro power plants (especially those of small scale), followed accordingly by PV power installations, comprise the least intensive energy solutions in terms of water use. As a result, application opportunities for these technologies across the mainland on the one hand and in certain areas of Crete on the other may alleviate the situation of local water scarcity met in the regions of West Macedonia, West Peloponnesus and Crete respectively. For this to occur however, development of an integrated decision tool that will also encompass -among other criteria- the water use intensity of different power generation technologies -comprising the research subject of a forthcoming study- is required for the examination of different future electricity generation scenarios.

ACKNOWLEDGMENTS

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